DEPARTMENT OF DEFENSE "ARMED WITH SCIENCE: RESEARCH AND APPLICATIONS FOR THE MODERN MILITARY" WEBCAST GUEST: GEOFF CHESTER, PUBLIC AFFAIRS OFFICER, U.S. NAVAL OBSERVATORY HOST: LIEUTENANT JENNIFER CRAGG, OFFICE OF THE SECRETARY OF DEFENSE FOR PUBLIC AFFAIRS DATE: WEDNESDAY, JANUARY 14, 2009

ANNOUNCER: Armed with Science: Research and Applications for the Modern Military is a bimonthly webcast that discusses cutting-edge science and technology, and how they apply to military operations. Each week we will interview scientists, administrators and operators to educate and inform our listeners about the importance of science and technology to the modern military.

LT. CRAGG: And, good afternoon. Welcome. You're listening to Episode 1 of "Armed with Science," for Wednesday, January 14th, 2009. Armed with Science is a bimonthly webcast, and we welcome you to our first show.

Today's guest is going to be Geoff Chester. He's actually the public affairs officer for the U.S. Naval Observatory. Geoff will be discussing the U.S. Naval Observatory's Master Clock, which actually is one of the most precise clocks in the world.

With that, sir -- or Geoff, I'm going to turn it over to you, if you want to add a couple things before we go on into some questions.

MR. CHESTER: No, it's just -- it's my pleasure to be here on this inaugural show, and I look forward to discussing what we do here at the U.S. Naval Observatory. It is a very interesting place to work.

LT. CRAGG: Great, great. And, one more thing, I'm your host, Lieutenant Jennifer Cragg. And a note to our listeners, if you have any questions for Geoff Chester, please go to Episode 1, and in the comment section please list your questions there. Geoff can go ahead and answer them at a later time.

So, my first question I'm sure our listeners are going to want to know is, what is the Master Clock at the Naval Observatory? And is an atomic -- and it is an atomic clock, what does that actually mean? Can you explain?

MR. CHESTER: Yes. First of all, let's talk about the concept of what a clock is to begin with. Clocks are devices that have been developed over the course of history to enable us to keep track of the passage of time. And, to me, the development of the concept of time, and keeping track of time, is really the hallmark of our intelligence as a species.

I think once people began to master time as a tool, if you will, it enabled the very basics of civilization to start -- the idea of having some way of regulating the planning and harvesting of crops, and ultimately the ability to create cities and centers where people could live together, and that sort of thing.

So, understanding the concept of a clock is really the key point that we need to begin with. And the basic idea behind a clock is that we have two components. We have something that we "technical types" call an oscillator, which is simply some sort of system that gives us a regular, rhythmic repetition and a counter. And we define intervals of time as a specific number of oscillations of whatever system that happens to be.

Now, for -- oh, centuries, there were things like water clocks, where water would drip out of a hole at the bottom of a tank. The most precision clocks for -- oh, the, since the mid-17th century, which were used pretty much up until the mid-20th century, were pendulum clocks. And everyone, I'm pretty sure, is used to or has seen somewhere along the line, you know, the grandfather clock with the stately pendulum ticking back and forth, and that sort of thing.

Atomic clocks are basically operating on the same principle. Now, they are not, you know, it's not like -- you don't have to worry about walking in a room full of atomic clocks and coming out the other end glowing. That's not the kind of use of the term "atomic" that we employ.

What atomic clocks are, are devices that take advantage of a natural oscillation in specific atoms of specific elements on the Periodic Table. And since atoms are very small, they can oscillate at extremely high frequencies. And we define a time scale in terms of a certain number of oscillations of a certain type of atom that take place in the course of one second.

So, the Master Clock here at the U.S. Naval Observatory is actually an ensemble of dozens of these devices. And we use a number of different kinds of devices because some are better at certain types of timekeeping applications than others. And we take a weighted average of the frequency output of all of these clocks to determine our base reference time scale.

Our clock is so precise that currently it will not gain or lose more than one second over the course of something on the order of three million years, which for most of us, I think, is pretty good.

LT. CRAGG: Well, thanks for going over that. I appreciate it.

Now, let's go into another level for our listeners. So, the -- (inaudible) -- international time scale is based on atomic time, which you already went over. What is the relationship to Greenwich Mean Time? Can you explain?

MR. CHESTER: Sure. The atomic time scale is what is used to define the time interval that is known as the second today. And back in 1967 work was done to take the frequency of a specific type of atomic clock, known as a Cesium Beam Frequency Standard, and tie that into the astronomically-defined time scales that had been used up until that time.

If you look at the history of timekeeping, there are intervals that we sort of take for granted now because they're ingrained into our day-to-day lives -- the day is 24 hours in length, and since there are 60 minutes in a hour, and 60 seconds in a minute, it therefore follows that there are 86,400 seconds in a day. Astronomically, this was defined as the mean interval from noon to noon over the course of a year. So, it was defined essentially by the rotation of the earth.

But the problem is that for very precise timekeeping applications, it's very bad physics to utilize a second that is defined this way because the earth is not something that rotates precisely the same, day in and day out. The earth, if you start to parse it into very, very small time intervals, is a really terrible timekeeper.

So, back in the 1950s and the 1960s, people began to look for more precise ways of determining this time interval known as the second. And in 1967, the world's physicists adopted a new value of the second which was no longer tied into the rotation of the earth, but rather it was defined as the duration of 9,192,631,770 cycles of radiation corresponding to the transition between two hyperfine levels of the ground state of the element cesium-133. Now, that's a big mouthful, but basically what we're measuring is a specific microwave frequency that is caused by this hyperfine level transition in this particular type of atom. This defines the atomic time scale.

Atomic time is completely independent of what the earth does. There is something, though, which is called "Universal Time," and a quantity which is known as "UT1" is basically the rotation speed of the earth today. And UT1 would essentially be the direct correlation to what we used to call "Greenwich Mean Time," because it's actually measuring time kept by the earth, referenced to the Prime Meridian of the world.

Well, today we keep -- the internationally-defined timescale is based on atomic time. And atomic time -- the day, in atomic time, is a little bit shorter than the time that is defined by earth rotation time. So, periodically, we have to coordinate these two time scales together, and this provides us what we call "Coordinated Universal Time," which is basically atomic time adjusted by incremental, integral leap seconds.

You may have heard about the leap-second that we inserted at the very end of the year 2008. This is done so that we can keep both the earth rotation time scale and the atomic time scale to within one second of each other.

So, Universal Time -- Coordinated Universal Time is sort of the modern-day equivalent of what used to be called Greenwich Mean Time. And, a lot of people still refer to it as Greenwich Mean Time because even though we have this wonderful new way of defining precisely when things take place, there are still people that like to work and go by tradition. So, even though the term "Greenwich Mean Time" is no longer a valid term, in terms of timekeeping, it is still very widely used in the world today.

LT. CRAGG: I'm sure our listeners will benefit from that -- from that explanation.

Our next question is, what makes the Navy's Master Clock special? Can you explain? MR. CHESTER: Our Master Clock system is the most robust of its kind in the world. There are approximately 50 scientific laboratories around the world that are concerned with timekeeping. Our atomic clock ensemble consists of about one-third of the operational atomic clocks that are currently deployed in the world.

For this reason, we contribute about one-third of the weighted average that goes into the international determination of Coordinated Universal Time.

So, from a kind of very bird's eye view, we are the majority contributor to that international definition and, essentially, the world is keeping our time.

Now, again, our time scale is very precise. We are required by the Department of Defense to maintain that time scale to a precision of better than one billionth of a second per day -- or, as we say in science-speak, "one nanosecond per day," averaged over the course of a year.

What this means is that we don't necessarily guarantee that every single second that comes out of this facility is going to be exactly 9,192,631,770 cycles of the transition of hyperfine states of cesium- 133, but we do guarantee that no two seconds that come out of here, over the course of a year, will differ from each other by more than one part in one billion.

There are actually two agencies in the United States that are responsible for timekeeping. One is the National Institute of Standards in Technology. They are charged with determining precisely how long one particular second is. They are the folks that engineers go to when they want to make sure that they are referencing the absolute definition of time, of length, et cetera, et cetera.

On the other hand, we are the agency that is responsible for a continuous, uninterrupted chronological time scale. So, in kind of a nutshell, you can think of N.I.S.T. as a stop-watch. It's great for measuring how long it takes an event to occur, but if you want to know exactly when that event occurred, you need a clock, and we are that clock.

Now, our clock system, in addition to contributing to the international definition of Coordinated Universal Time, is also used as a reference for many, many different systems of time that are required for us to carry out our day-to-day lives. Things like the ability of computer networks, like the Internet, to harmoniously and continuously transfer data most efficiently between any two computers on the network.

We are the time scale reference for the Global Positioning System. Timing is what allows us to determine position here on the surface of the earth. So, there are many, many ways that our clock actually ties almost directly into the way people go about their day- to-day lives now.   LT. CRAGG: So, essentially, this clock is a really precise clock, and it's very much needed in the Navy?

MR. CHESTER: Absolutely. Anything that has to do with -- anything that has to do with timing. And today, timing is literally everything.

Information is transmitted on a continual basis in little digital packets. If you, for instance -- well, let's take something as mundane as calling -- you know, picking up your cell phone and calling a friend across town or across the country. Cell phone communications today are primarily transmitted through digital networks.

So, so you talk into your cell phone, and when your analog signal -- a cell phone is basically like a little walkie-talkie, but when your analog voice signal gets to your cell phone service provider, it gets fed into a computer, where it gets diced up into a bunch of little ones and zeroes. Those ones and zeroes then get packaged into little data packets that then are sent out to the other end of the line -- the receiving end, and they are sort of shot out over the network.

And the network will continually change the way it routes those packets because it's constantly responding to message, data, volume, that sort of thing. So, those packets of information will get to the destination computer probably in a different order from which they were transmitted initially.

So, how does the computer at the other end understand how to put the data back together into something that is intelligible? It looks for a digital time stamp at the head of each little data packet, and it arranges the data according to that sequential time stamp. And then it can decode the data, turn that data into something sounding like your voice, and send it out to the cell phone of the person that you're talking to.

If there is no precise means of synchronizing the computers on both ends of the operation, as well as a means of assigning sequential time stamps, the whole system basically breaks down and nobody can communicate with anybody.

LT. CRAGG: Now, one of the things -- when you were talking I was thinking is, a lot of people might think the Naval Observatory just primarily does astronomy. So, why is the clock maintained by the Naval Observatory?

MR. CHESTER: Well, astronomy plays a very big part in timekeeping. Up until the age of the atomic clocks, time scales were defined astronomically. We have actually preserved in the lobby here, of the main building at the observatory, a very specialized kind of telescope which is known as a "transit circle." And that telescope made very specific kinds of observations that allowed us to determine, with great precision, on the order of about a thousandth of a second or so, what the mean rotation speed -- or mean rotation duration of the earth was, to define the astronomically-defined second that was used up until 1967.

That time scale was, in turn, used to determine the running rates of chronometers, which are vital in the art of celestial navigation. And celestial navigation, up until the era of the Global Positioning System, was the way that Navy vessels, commercial vessels, transatlantic yachtsmen, all those folks found their way around the planet.

So, tying in an astronomical reference to a time scale is vital for all aspects of navigation.

Today, it's even more vital than ever because the earth is very slowly and very slightly changing its speed of rotation and it's changing its axis of rotation -- very, very small effects that take place over long periods of time. But even using something like the Global Positioning System as a reference, you have to know precisely what the earth is doing underneath that constellation of satellites, exactly what the earth's motions and rotation speed are doing at any particular time.

In order to determine this, we have to establish a reference frame that is based on the most distant objects that we can find in the universe. These are called "Quasars," and we actually observe them with radio telescopes around the world. The Naval Observatory determines and essentially keeps what we call the International Celestial Reference Frame. And this is basically like the network of benchmarks that would be set up for surveying on land. These are, sort of, cosmic benchmarks against which we can reference the positions of everything else in the universe.

LT. CRAGG: And my last and final question I wanted to find out is, I heard that a new clock was being built at that Observatory. Can you tell us a little bit about it?

MR. CHESTER: This is a very exciting project that we have going on here. We have had essentially our Master Clock system running here, in its current form, since probably the late 1970s, the early 1980s. And it really hasn't changed much. Our requirement to keep time to one billionth of a second per day, or better, has been around for 20 years or so.

The problem is that technology is beginning to catch up to us. When this system first came into being, the types of technology that needed to take advantage of ultra-precise time just plain didn't exist. We were probably six -- five or six orders of magnitude beyond the demands of the most stringent technology of the day.

But, as the digital world has evolved, and the technology for that has evolved over the years, that technology is catching up to the best that we can do. And today there are technologies out there which have timing requirements that are perhaps only two orders of magnitude away from the best that we can provide. So, it is incumbent for us to stay as far ahead of the curve as possible so that we can provide the best available timing reference on the planet. So, we are actually building here at the Observatory -- we actually have developed and built the hardware, right here at our facility, of a new type of atomic clock.

Now, this clock has a number of similarities to the older cesium clocks, but since we are not a standards laboratory like our friends at N.I.S.T. are, we are not bound to use the cesium atom as a reference oscillator. So, instead we use an element called "rubidium." Now, rubidium doesn't oscillate. It doesn't vibrate as fast as the cesium atom does. It's only about 6 billion cycles per second, or somewhere in that vicinity. But, rubidium atoms are smaller than cesium atoms, and so they are easier to manipulate.

And one of the things that we want to try to do -- one of the ways that you measure the frequencies of these atomic transitions is you fire the atoms into a microwave cavity, bombard them with microwave radiation at that magic resonant frequency, and sort of see what you get at the other end.

The problem with conventional cesium-beam clocks is that the cesium atoms spend a very small amount of time in the microwave cavity telling us what their frequency is. The new clock that we are developing is something that's called a "fountain clock."

We actually use lasers to trap and cool rubidium atoms to a few millionths of a degree above absolute zero; and then, using light pressure from lasers, we can toss them in a lazy path up through a microwave cavity that's about one meter tall -- and they go up and down at the acceleration of gravity, spending about a half a second going up, and a half a second going down. And we have a opportunity to get a nice, long look at their resonant frequency.

This clock is ultra stable compared to any of the other devices we've ever built before. It gives us a very high reliability statement on exactly what the oscillation frequency of these atoms are, and it will allow us to keep, ultimately, a much better time scale than what we can keep today.

So, instead of one billionth of a second per day, when we implement these clocks operationally -- which will probably be some time in 2010, our clock will then be keeping time to a precision on the order of 100 trillionths of a second per day. So, we will be that much further ahead of the curve of the technologies that need to take advantage of precise time.

LT. CRAGG: That is really amazing -- that's amazing that you said that. It was great, actually, talking to you today. I thought you provided a great rundown of the Master Clock. Is there anything else I didn't ask you that you wanted to add.

And, before you do that, if anybody's interested to learn more about the U.S. Naval Observatory, can you give them the web address? MR. CHESTER: The website is: www.usno.Navy.mil. And we have descriptions there of the various forms of time scales, how the clocks work, how the Master Clock system works. It's pretty educational.

I would say that the number one way that people can probably relate to us these days is more and more folks are starting to use Global Positioning System receivers as ways to find their way around town, that sort of thing. Global Positioning System essentially works by measuring differences in atomic clocks that are on-board a constellation 24 satellites that are in orbit over the earth.

Those atomic clocks have to be rated -- they have to be compared to a reference time scale because they're all free-running clocks, and just as the chronometers of old, they don't all run at exactly the same rate. So, they are compared to our Master Clock every day, and the data from those intercomparisons are then used to make very small corrections that are transmitted with the satellite timing data to your GPS receiver to tell you where you are.

In one billionth of a second a beam of light goes about 30 centimeters, or one foot. If your GPS receiver is able to tell you where you are to a precision on the order of 10 meters, or 30 feet, that means that you are resolving time down to about 30 billionths of a second with your GPS receiver.

People ask if, you know, what's time about? And I just tell them timing is everything.

LT. CRAGG: That was a great explanation.

And, with that, that wraps up today's show, I guess our -- launch of our first show, Episode 1.

So, please join us on January 28th when we will continue with "Armed with Science," and we will speak with Mike Jeffries. He's the technical director at Fleet Survey Teams, and he will discuss the techniques and tools of ocean-bottom mapping, and a variety of other topics as well.

So, for our listeners, thank you for tuning in to Episode 1, and we hope that you come back.

And, to Mr. Chester, just thank you so much for being our first guest.

MR. CHESTER: My pleasure.

LT. CRAGG: Bye bye.

MR. CHESTER: Bye bye. END.